

## New Physics in the Flavour Sector

ANDREAS CRIVELLIN

*Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland*



Several experiments observed deviations from the Standard Model (SM) in the flavour sector: LHCb found a  $4 - 5\sigma$  discrepancy compared to the SM in  $b \rightarrow s\mu^+\mu^-$  transitions (recently supported by an Belle analysis) and CMS reported a non-zero measurement of  $h \rightarrow \mu\tau$  with a significance of  $2.4\sigma$ . Furthermore, BELLE, BABAR and LHCb founds hints for the violation of flavour universality in  $B \rightarrow D^{(*)}\tau\nu$ . In addition, there is the long-standing discrepancy in the anomalous magnetic moment of the muon. Interestingly, all these anomalies are related to muons and taus, while the corresponding electron channels seem to be SM like. This suggests that these deviations from the SM might be correlated and we briefly review some selected models providing simultaneous explanations.

### 1 Introduction

The discovery the Higgs at the LHC provided the final ingredient of the SM. While no direct evidence for physics beyond the SM was found during the first LHC run, there are some interesting indirect hints for NP in the flavor sector, mainly in semileptonic decays of  $B$ -mesons, the SM-forbidden decay  $h \rightarrow \mu\tau$  of the Higgs boson and the long-lasting discrepancy in the anomalous magnetic moment (AMM) of the muon<sup>a</sup>.

$b \rightarrow s\ell^+\ell^-$ : Deviations from the SM found by LHCb<sup>4</sup> in the decay  $B \rightarrow K^*\mu^+\mu^-$  arise mainly in an angular observable called  $P_5'$ <sup>5</sup>, with a significance of  $2-3\sigma$  depending on assumptions made for the hadronic uncertainties<sup>6,7,8</sup>. This measurement recently received support from a (less precise) BELLE measurement<sup>9</sup>. In the decay  $B_s \rightarrow \phi\mu^+\mu^-$ , LHCb also uncovered<sup>10</sup> deviations compared to the SM prediction from lattice QCD<sup>11,12</sup> of  $3.5\sigma$  significance<sup>7</sup>. LHCb has further observed lepton flavor universality violation (LFUV) in  $B \rightarrow K\ell^+\ell^-$  decays<sup>13</sup> across the dilepton invariant-mass-squared range  $1\text{ GeV}^2 < m_{\ell\ell}^2 < 6\text{ GeV}^2$ . Here, the measured ratio branching fraction ratio  $R(K) = \frac{\text{Br}[B \rightarrow K\mu^+\mu^-]}{\text{Br}[B \rightarrow Ke^+e^-]}$  disagrees with the theoretically clean SM prediction by  $2.6\sigma$ . Combining these observables with other  $b \rightarrow s$  transitions, it is found that NP is preferred over the SM by  $4-5\sigma$ <sup>14,15,16</sup>.

$B \rightarrow D^{(*)}\tau\nu_\tau$ : Hints for LFUV in these modes were observed first by the BaBar collaboration<sup>17</sup> in 2012. These measurements have been confirmed by BELLE<sup>18,19</sup> and LHCb has

<sup>a</sup>We do not discuss the anomaly in  $e'/e$ <sup>1</sup> here for which possible solutions include  $Z'$  bosons<sup>2</sup> or the MSSM<sup>3</sup>.

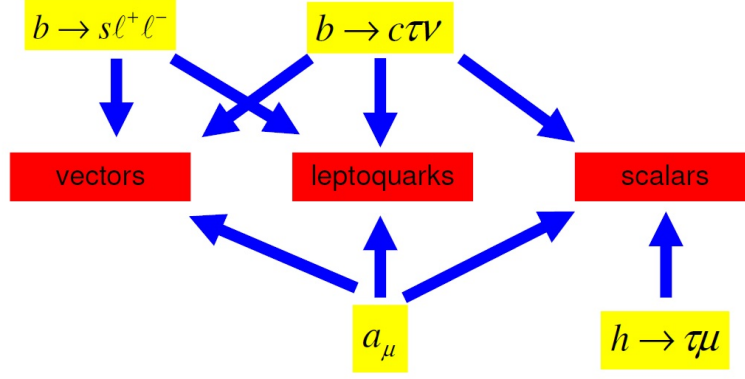


Figure 1: Schematic picture of the implications for new particles from the various anomalies.

remeasured  $B \rightarrow D^* \tau \nu_\tau$ <sup>20</sup>. For the ratio  $R(X) \equiv \text{Br}[B \rightarrow X \tau \nu_\tau] / \text{Br}[B \rightarrow X \ell \nu_\ell]$ , the current HFAG average<sup>21</sup> of these measurements is  $R(D)_{\text{exp}} = 0.397 \pm 0.040 \pm 0.028$ ,  $R(D^*)_{\text{exp}} = 0.316 \pm 0.016 \pm 0.010$ . Comparing these results to the SM predictions<sup>22</sup>  $R_{\text{SM}}(D) = 0.297 \pm 0.017$  and  $R_{\text{SM}}(D^*) = 0.252 \pm 0.003$ , there is a combined discrepancy of  $4.0\sigma$ <sup>21</sup>.

$h \rightarrow \mu\tau$ : In the Higgs sector, CMS has presented results for a search for the lepton-flavor-violating (LFV) decay mode  $h \rightarrow \mu\tau$ , with a preferred value<sup>23</sup>  $\text{Br}[h \rightarrow \mu\tau] = (0.84^{+0.39}_{-0.37})\%$ . This is consistent with the less precise ATLAS measurement<sup>24</sup>, giving a combined significance for NP of  $2.6\sigma$ , since such a decay is forbidden in the SM. This decay mode is of considerable interest because it hints at LFV in the charged-lepton sector, whereas up to now, LFV has only been observed in the neutrino sector via oscillations.

$a_\mu$ : The AMM of the muon  $a_\mu \equiv (g-2)_\mu/2$ , provides another motivation for NP connected to muons. The experimental value of  $a_\mu$  is completely dominated by the Brookhaven experiment E821<sup>25</sup> and is given by  $a_\mu^{\text{exp}} = (116\,592\,091 \pm 54 \pm 33) \times 10^{-11}$ , where the first error is statistical and the second systematic. The SM prediction is<sup>26</sup>  $a_\mu^{\text{SM}} = (116\,591\,855 \pm 59) \times 10^{-11}$ , where almost the entire uncertainty is due to hadronic effects. This amounts to a discrepancy between the SM and experimental values of  $\Delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (236 \pm 87) \times 10^{-11}$ , i.e. a  $2.7\sigma$  deviation<sup>b</sup>.

## 2 Explanations

$b \rightarrow s \ell^+ \ell^-$ : Here a flavour changing neutral current is required which can be naturally generated at tree-level by a  $Z'$  vector bosons<sup>27,28,29,30,31,32,33,34,35,36</sup> or by leptoquarks<sup>37,38,39,40,41,42</sup>.

$B \rightarrow D^{(*)} \tau \nu_\tau$ : Here a tree-level NP contribution is required in order to generate the desired effect of the order of 25% compared to the SM. Charged Higgses<sup>43,44,45,46,47</sup> are one possibility, leading to large effects in the  $q^2$  distribution. In addition, leptoquarks provide a valid explanation<sup>48,49,50,40,41,51,52,42</sup> but also charged vector bosons are possible<sup>53</sup>.

$a_\mu$ : NP in  $b \rightarrow s \mu^+ \mu^-$  should also contribute to the AMM of the muon. Explanations besides supersymmetry (see for example Ref. <sup>54</sup> for a review) include leptoquarks<sup>55,56</sup>, new scalar contributions in two-Higgs-doublet models (2HDM)<sup>57,47</sup>, and very light  $Z'$  bosons<sup>58,59</sup>.

$h \rightarrow \mu\tau$ : Since the  $B$  physics anomalies are related to  $\tau$  and  $\mu$  leptons, a connection to  $h \rightarrow \mu\tau$  seems plausible. As the central value for the  $h \rightarrow \mu\tau$  branching ratio is large, loop effects are in general not sufficient to generate the desired effect<sup>60</sup>. Furthermore, also adding only vector-like fermions is not sufficient as the bounds from  $\tau \rightarrow 3\mu$  and  $\tau \rightarrow \mu\gamma$  are too stringent<sup>61</sup>. Therefore, introducing additional scalars is the most popular option (see for example<sup>62,63,31,60</sup>).

<sup>b</sup>Less conservative estimates even lead to discrepancies up to  $3.6\sigma$  in  $a_\mu$

### 3 Selected models for simultaneous explanations of anomalies

#### Multi Higgs $L_\mu - L_\tau$ model: $h \rightarrow \tau\mu$ and $b \rightarrow s\mu^+\mu^-$ <sup>31,32</sup>

Adding to a gauged  $L_\mu - L_\tau$  model with vector like quarks <sup>30</sup> a second Higgs doublet with  $L_\mu - L_\tau$  charge 2 can naturally give an effect in  $h \rightarrow \tau\mu$  via a mixing among the neutral CP-even components of the scalar doublets. In this setup a  $Z'$  boson, which can explain the  $b \rightarrow s\mu^+\mu^-$  anomalies, gives sizable effects in  $\tau \rightarrow 3\mu$  which are potentially observable at LHCb and especially at BELLE II. One can avoid the introduction of vector-like quarks by assigning horizontal charges to quarks as well <sup>32</sup>. Then, the effects in  $b \rightarrow s$ ,  $b \rightarrow d$  and  $s \rightarrow d$  transitions are related in an MFV-like way by CKM elements and the  $Z'$  can have an observable cross section at the LHC.

#### Leptoquarks: $b \rightarrow s\mu^+\mu^-$ and $b \rightarrow c\tau\nu$ <sup>41</sup>

While in  $b \rightarrow c\tau\nu$  both leptoquarks and the SM contribute at tree-level, in  $b \rightarrow s\mu^+\mu^-$  one compares a potential tree-level NP contribution to a loop effect<sup>c</sup>. However, as  $b \rightarrow c\tau\nu$  involves three times the third generation (assuming that the neutrino is of tau flavour in order to get interference with the SM contribution) but  $b \rightarrow s\mu^+\mu^-$  only once. Therefore, leptoquarks with hierarchical flavour structure, i.e. predominantly coupling to the third generation <sup>64,65</sup>, can explain simultaneously  $b \rightarrow s\mu^+\mu^-$  and  $b \rightarrow c\tau\nu$  in case of a  $C_9 = -C_{10}$  (left-handed quark and lepton current) solution for  $b \rightarrow s\mu^+\mu^-$ . In this case one predicts sizable effects in  $B \rightarrow K^{(*)}\tau\tau$ ,  $B_s \rightarrow \tau^+\tau^-$  and  $B_s \rightarrow \mu^+\mu^-$  below the SM, while the effects in  $b \rightarrow s\tau\mu$  are at most of the order of  $10^{-5}$ .

#### 2HDM X: $a_\mu$ and $b \rightarrow c\tau\nu$ <sup>47</sup>

In a 2HDM of type X, the couplings of the additional Higgses to charged leptons are enhanced by  $\tan\beta$ . As, unlike for the 2HDM II, this enhancement is not present for quarks, the direct LHC bounds on  $H^0, A^0 \rightarrow \tau^+\tau^-$  are not very stringent and also  $b \rightarrow s\gamma$  poses quite weak constraints. Therefore, the additional Higgses can be light which, together with the  $\tan\beta$  enhanced couplings to muons, allows for an explanation of  $a_\mu$ . If one adds couplings of the lepton-Higgs-doublet to third generation quarks, one can explain  $b \rightarrow c\tau\nu$  as well by a charged Higgs exchange. In case of a simultaneous explanation of  $a_\mu$  and  $b \rightarrow c\tau\nu$  (without violating bounds from  $\tau \rightarrow \mu\nu\nu$ ) within this model, sizable branching ratios (reaching even the % level) for  $t \rightarrow Hc$ , with  $m_H \approx 50 - 100$  GeV and decaying mainly to  $\tau\tau$ , are predicted. Again, such a signature could be observed at the LHC.

#### $L_\mu - L_\tau$ flavon model: $a_\mu$ , $h \rightarrow \tau\mu$ and $b \rightarrow s\mu^+\mu^-$ <sup>66</sup>

In this model one adds vector-like leptons to the gauged  $L_\mu - L_\tau$  model of Ref. <sup>30</sup> and one can explain  $h \rightarrow \tau\mu$  via a mixing of the flavon (the scalar which breaks  $L_\mu - L_\tau$ ) with the SM Higgs. Furthermore, one can account for  $a_\mu$  by loops involving the flavon and vector-like leptons without violating the  $\tau \rightarrow \mu\gamma$  bounds as this decay is protected by the  $L_\mu - L_\tau$  symmetry. Despite the effects already present in the model of Ref. <sup>31</sup>, one expects order one effects in  $h \rightarrow \mu^+\mu^-$  detectable with the high luminosity LHC.

### 4 Conclusions

In these proceedings we reviewed the anomalies in the flavour sector related to charged leptons together with some of their possible explanations. Interestingly, all anomalies involve muons and/or taus while the corresponding electron channels seem to agree with the SM predictions. This coherent picture of lepton flavour (universality) violation<sup>d</sup> agrees with the stringent LEP constraints and suggests that the anomalies could be related, hinting at an unified explanation within a NP model. In Fig. 1 we show in a schematic way which relations among the anomalies and new particles arise. Specific NP models can of course include the addition several new

<sup>c</sup>Alternatively, there is one leptoquark representation for which one can explain  $b \rightarrow s\mu^+\mu^-$  by a loop effect and  $b \rightarrow c\tau\nu$  at tree-level in the case on anarchic couplings <sup>51</sup> and even explain the AMM of the muon.

<sup>d</sup>For the implications in Kaon decays see <sup>67</sup>.

particles, potentially explain all anomalies and predict correlations among them and with other observables or processes detectable in future experiments.

## Acknowledgments

A.C. thanks the organizers for the invitation to *Moriond QCD* and for the opportunity to present these results. This work is supported by an Ambizione grant of the Swiss National Science Foundation.

1. Andrzej J. Buras, Martin Gorbahn, Sebastian Jger, and Matthias Jamin. Improved anatomy of  $\gamma$  in the Standard Model. *JHEP*, 11:202, 2015.
2. Andrzej J. Buras and Fulvia De Fazio.  $\varepsilon'/\varepsilon$  in 331 Models. *JHEP*, 03:010, 2016.
3. Teppei Kitahara, Ulrich Nierste, and Paul Tremper. Supersymmetric explanation of CP violation in  $K \rightarrow \pi\pi$  decays. 2016.
4. Roel Aaij et al. Angular analysis of the  $B^0 \rightarrow K^{*0}\mu^+\mu^-$  decay using 3 fb $^{-1}$  of integrated luminosity. *JHEP*, 02:104, 2016.
5. Sebastien Descotes-Genon, Tobias Hurth, Joaquim Matias, and Javier Virto. Optimizing the basis of  $B \rightarrow K^*\ell^+\ell^-$  observables in the full kinematic range. *JHEP*, 1305:137, 2013.
6. Sbastien Descotes-Genon, Lars Hofer, Joaquim Matias, and Javier Virto. On the impact of power corrections in the prediction of  $B \rightarrow K^*\mu^+\mu^-$  observables. *JHEP*, 1412:125, 2014.
7. Wolfgang Altmannshofer and David M. Straub. New physics in  $b \rightarrow s$  transitions after LHC run 1. *Eur. Phys. J.*, C75(8):382, 2015.
8. Sebastian Jger and Jorge Martin Camalich. Reassessing the discovery potential of the  $B \rightarrow K^*\ell^+\ell^-$  decays in the large-recoil region: SM challenges and BSM opportunities. *Phys. Rev.*, D93(1):014028, 2016.
9. A. Abdesselam et al. Angular analysis of  $B^0 \rightarrow K^*(892)^0\ell^+\ell^-$ . In *LHCski 2016 Obergurgl, Tyrol, Austria, April 10-15, 2016*, 2016.
10. Roel Aaij et al. Angular analysis and differential branching fraction of the decay  $B_s^0 \rightarrow \phi\mu^+\mu^-$ . *JHEP*, 09:179, 2015.
11. Ronald R. Horgan, Zhaofeng Liu, Stefan Meinel, and Matthew Wingate. Calculation of  $B^0 \rightarrow K^{*0}\mu^+\mu^-$  and  $B_s^0 \rightarrow \phi\mu^+\mu^-$  observables using form factors from lattice QCD. *Phys.Rev.Lett.*, 112:212003, 2014.
12. R. R. Horgan, Z. Liu, S. Meinel, and M. Wingate. Rare  $B$  decays using lattice QCD form factors. *PoS, LATTICE2014*:372, 2015.
13. Roel Aaij et al. Test of lepton universality using  $B^+ \rightarrow K^+\ell^+\ell^-$  decays. *Phys.Rev.Lett.*, 113(15):151601, 2014.
14. Wolfgang Altmannshofer and David M. Straub. Implications of  $b \rightarrow s$  measurements. 2015.
15. Sbastien Descotes-Genon, Lars Hofer, Joaquim Matias, and Javier Virto. Global analysis of  $b \rightarrow s\ell\ell$  anomalies. 2015.
16. T. Hurth, F. Mahmoudi, and S. Neshatpour. On the anomalies in the latest LHCb data. 2016.
17. J. P. Lees et al. Evidence for an excess of  $\bar{B} \rightarrow D^{(*)}\tau^-\bar{\nu}_\tau$  decays. *Phys. Rev. Lett.*, 109:101802, 2012.
18. M. Huschle et al. Measurement of the branching ratio of  $\bar{B} \rightarrow D^{(*)}\tau^-\bar{\nu}_\tau$  relative to  $\bar{B} \rightarrow D^{(*)}\ell^-\bar{\nu}_\ell$  decays with hadronic tagging at Belle. *Phys. Rev.*, D92(7):072014, 2015.
19. A. Abdesselam et al. Measurement of the branching ratio of  $\bar{B}^0 \rightarrow D^{*+}\tau^-\bar{\nu}_\tau$  relative to  $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$  decays with a semileptonic tagging method. 2016.
20. Roel Aaij et al. Measurement of the ratio of branching fractions  $\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\tau^-\bar{\nu}_\tau)/\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\mu^-\bar{\nu}_\mu)$ . *Phys. Rev. Lett.*, 115(11):111803, 2015. [Addendum: *Phys. Rev. Lett.*115,159901(2015)].

21. Y. Amhis et al. Averages of  $b$ -hadron,  $c$ -hadron, and  $\tau$ -lepton properties as of summer 2014. 2014.
22. Svjetlana Fajfer, Jernej F. Kamenik, and Ivan Nišandžić. On the  $B \rightarrow D^* \tau \bar{\nu}_\tau$  Sensitivity to New Physics. *Phys. Rev.*, D85:094025, 2012.
23. Vardan Khachatryan et al. Search for lepton-flavour-violating decays of the Higgs boson. 2015.
24. Georges Aad et al. Search for lepton-flavour-violating  $H \rightarrow \mu\tau$  decays of the Higgs boson with the ATLAS detector. 2015.
25. G.W. Bennett et al. Final Report of the Muon E821 Anomalous Magnetic Moment Measurement at BNL. *Phys. Rev.*, D73:072003, 2006.
26. Gilberto Colangelo, Martin Hoferichter, Andreas Nyffeler, Massimo Passera, and Peter Stoffer. Remarks on higher-order hadronic corrections to the muon  $g-2$ . *Phys. Lett.*, B735:90–91, 2014.
27. Sebastien Descotes-Genon, Joaquim Matias, and Javier Virto. Understanding the  $B \rightarrow K^* \mu^+ \mu^-$  Anomaly. *Phys.Rev.*, D88(7):074002, 2013.
28. Rhorry Gauld, Florian Goertz, and Ulrich Haisch. On minimal  $Z'$  explanations of the  $B \rightarrow K^* \mu^+ \mu^-$  anomaly. *Phys.Rev.*, D89:015005, 2014.
29. Andrzej J. Buras, Fulvia De Fazio, and Jennifer Girrbach. 331 models facing new  $b \rightarrow s \mu^+ \mu^-$  data. *JHEP*, 1402:112, 2014.
30. Wolfgang Altmannshofer, Stefania Gori, Maxim Pospelov, and Itay Yavin. Quark flavor transitions in  $L_\mu - L_\tau$  models. *Phys.Rev.*, D89(9):095033, 2014.
31. Andreas Crivellin, Giancarlo D’Ambrosio, and Julian Heeck. Explaining  $h \rightarrow \mu^\pm \tau^\mp$ ,  $B \rightarrow K^* \mu^+ \mu^-$  and  $B \rightarrow K \mu^+ \mu^- / B \rightarrow K e^+ e^-$  in a two-Higgs-doublet model with gauged  $L_\mu - L_\tau$ . *Phys. Rev. Lett.*, 114:151801, 2015.
32. Andreas Crivellin, Giancarlo D’Ambrosio, and Julian Heeck. Addressing the LHC flavor anomalies with horizontal gauge symmetries. *Phys. Rev.*, D91(7):075006, 2015.
33. Christoph Niehoff, Peter Stangl, and David M. Straub. Violation of lepton flavour universality in composite Higgs models. *Phys. Lett.*, B747:182–186, 2015.
34. D. Aristizabal Sierra, Florian Staub, and Avelino Vicente. Shedding light on the  $b \rightarrow s$  anomalies with a dark sector. *Phys. Rev.*, D92(1):015001, 2015.
35. Andreas Crivellin, Lars Hofer, Joaquim Matias, Ulrich Nierste, Stefan Pokorski, and Janusz Rosiek. Lepton-flavour violating  $B$  decays in generic  $Z'$  models. *Phys. Rev.*, D92(5):054013, 2015.
36. Alejandro Celis, Javier Fuentes-Martin, Martn Jung, and Hugo Serodio. Family nonuniversal  $Z$  models with protected flavor-changing interactions. *Phys. Rev.*, D92(1):015007, 2015.
37. Ben Gripaios, Marco Nardecchia, and S. A. Renner. Composite leptoquarks and anomalies in  $B$ -meson decays. *JHEP*, 05:006, 2015.
38. Damir Beeirevic, Svjetlana Fajfer, and Nejc Konik. Lepton flavor nonuniversality in  $bs^{+-}$  processes. *Phys. Rev.*, D92(1):014016, 2015.
39. Ivo de Medeiros Varzielas and Gudrun Hiller. Clues for flavor from rare lepton and quark decays. *JHEP*, 06:072, 2015.
40. Rodrigo Alonso, Benjamn Grinstein, and Jorge Martin Camalich. Lepton universality violation and lepton flavor conservation in  $B$ -meson decays. *JHEP*, 10:184, 2015.
41. Lorenzo Calibbi, Andreas Crivellin, and Toshihiko Ota. Effective field theory approach to  $b \rightarrow s \ell \ell^{(\prime)}$ ,  $B \rightarrow K^{(*)} \nu \bar{\nu}$  and  $B \rightarrow D^{(*)} \tau \nu$  with third generation couplings. *Phys. Rev. Lett.*, 115(18):181801, 2015.
42. Riccardo Barbieri, Gino Isidori, Andrea Pattori, and Fabrizio Senia. Anomalies in  $B$ -decays and  $U(2)$  flavour symmetry. 2015.
43. Andreas Crivellin, Christoph Greub, and Ahmet Kokulu. Explaining  $B \rightarrow D \tau \nu$ ,  $B \rightarrow D^* \tau \nu$  and  $B \rightarrow \tau \nu$  in a 2HDM of type III. *Phys. Rev.*, D86:054014, 2012.

44. Minoru Tanaka and Ryoutaro Watanabe. New physics in the weak interaction of  $\bar{B} \rightarrow D^{(*)}\tau\bar{\nu}$ . *Phys. Rev.*, D87(3):034028, 2013.
45. Alejandro Celis, Martin Jung, Xin-Qiang Li, and Antonio Pich. Sensitivity to charged scalars in  $B \rightarrow D^{(*)}\tau\nu_\tau$  and  $B \rightarrow \tau\nu_\tau$  decays. *JHEP*, 01:054, 2013.
46. Andreas Crivellin, Ahmet Kokulu, and Christoph Greub. Flavor-phenomenology of two-Higgs-doublet models with generic Yukawa structure. *Phys. Rev.*, D87(9):094031, 2013.
47. Andreas Crivellin, Julian Heeck, and Peter Stoffer. A perturbed lepton-specific two-Higgs-doublet model facing experimental hints for physics beyond the Standard Model. *Phys. Rev. Lett.*, 116(8):081801, 2016.
48. Svjetlana Fajfer, Jernej F. Kamenik, Ivan Nišandžić, and Jure Zupan. Implications of Lepton Flavor Universality Violations in B Decays. *Phys. Rev. Lett.*, 109:161801, 2012.
49. N. G. Deshpande and A. Menon. Hints of R-parity violation in B decays into  $\tau\nu$ . *JHEP*, 01:025, 2013.
50. Yasuhito Sakaki, Minoru Tanaka, Andrey Tayduganov, and Ryoutaro Watanabe. Testing leptoquark models in  $\bar{B} \rightarrow D^{(*)}\tau\bar{\nu}$ . *Phys. Rev.*, D88(9):094012, 2013.
51. Martin Bauer and Matthias Neubert. One Leptoquark to Rule Them All: A Minimal Explanation for  $R_{D^{(*)}}$ ,  $R_K$  and  $(g-2)_\mu$ . 2015.
52. Svjetlana Fajfer and Nejc Konik. Vector leptoquark resolution of  $R_K$  and  $R_{D^{(*)}}$  puzzles. *Phys. Lett.*, B755:270–274, 2016.
53. Admir Greljo, Gino Isidori, and David Marzocca. On the breaking of Lepton Flavor Universality in B decays. *JHEP*, 07:142, 2015.
54. Dominik Stöckinger. The Muon Magnetic Moment and Supersymmetry. *J. Phys.*, G34:R45–R92, 2007.
55. Debrupa Chakraverty, Debajyoti Choudhury, and Anindya Datta. A Nonsupersymmetric resolution of the anomalous muon magnetic moment. *Phys. Lett.*, B506:103–108, 2001.
56. King-man Cheung. Muon anomalous magnetic moment and leptoquark solutions. *Phys. Rev.*, D64:033001, 2001.
57. Alessandro Broggio, Eung Jin Chun, Massimo Passera, Ketan M. Patel, and Sudhir K. Vempati. Limiting two-Higgs-doublet models. *JHEP*, 11:058, 2014.
58. Paul Langacker. The Physics of Heavy  $Z'$  Gauge Bosons. *Rev.Mod.Phys.*, 81:1199–1228, 2009.
59. Julian Heeck and Werner Rodejohann. Gauged  $L_\mu - L_\tau$  Symmetry at the Electroweak Scale. *Phys.Rev.*, D84:075007, 2011.
60. Ilja Dorner, Svjetlana Fajfer, Admir Greljo, Jernej F. Kamenik, Nejc Konik, and Ivan Niandic. New Physics Models Facing Lepton Flavor Violating Higgs Decays at the Percent Level. *JHEP*, 06:108, 2015.
61. Adam Falkowski, David M. Straub, and Avelino Vicente. Vector-like leptons: Higgs decays and collider phenomenology. *JHEP*, 1405:092, 2014.
62. Miguel D. Campos, A. E. Cárcamo Hernández, Heinrich Päs, and Erik Schumacher. Higgs  $\rightarrow \mu\tau$  as an indication for  $S_4$  flavor symmetry. 2014.
63. Julian Heeck, Martin Holthausen, Werner Rodejohann, and Yusuke Shimizu. Higgs in Abelian and non-Abelian flavor symmetry models. *Nucl. Phys.*, B896:281–310, 2015.
64. Sheldon L. Glashow, Diego Guadagnoli, and Kenneth Lane. Lepton Flavor Violation in B Decays? *Phys. Rev. Lett.*, 114:091801, 2015.
65. Bhuvanajyoti Bhattacharya, Alakabha Datta, David London, and Shanmuka Shivashankara. Simultaneous Explanation of the  $R_K$  and  $R(D^{(*)})$  Puzzles. *Phys.Lett.*, B742:370–374, 2015.
66. Wolfgang Altmannshofer, Marcela Carena, and Andreas Crivellin. A  $L_\mu - L_\tau$  theory of Higgs flavor violation and  $(g-2)_\mu$ . 2016.
67. Andreas Crivellin, Giancarlo D’Ambrosio, Martin Hoferichter, and Lewis C. Tunstall. Lepton flavor (universality) violation in rare kaon decays. *Phys. Rev.*, D93:074038, 2016.